Elevational diversity of arrow bamboo (*Fargesia spathacea*) communities on Mount Shennongjia in Central China

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Abstract: Altitudinal changes in species richness, species diversity, species evenness, life-form spectrum, and community structure of arrow bamboo (*Fargesia spathacea*) were studied within 11 plots from 1 500 m to 2 600 m asl on Mount Shennongjia in Central China. From the lowest plot (1 680 m) to the highest one (2 570 m), vascular plants declined from 30 to 7 species, following a linear model of $Y = 55.99 - 1.83X$ (*d.f.* = 9, *F*-value = 48.64, $r^2 = 0.84$, $P < 0.001$); species diversity reduced from 3.13 to 1.78, following a linear model of $Y = 4.67 - 0.10X$ (*d.f.* = 9, *F*-value = 22.82, $r^2 = 0.72$, $P = 0.001$); species evenness varied from 0.83 to 0.99, but presented little relationship to the altitude ($r = 0.112$, $P = 0.742$). In the life-form spectra, with the increase of altitude, the percentage of annual plants ($r = 0.60$), underground bulb perennials ($r = 0.40$), and big trees ($r = 0.35$) tended to increase; shrubs ($r = -0.52$) and middle-sized trees ($r = -0.45$) tended to decline; perennial grasses ($r = 0.04$) and semi-shrubs ($r = 0.03$) were not strongly related to the altitudinal gradient. Arrow bamboo communities could be classified into five groups: bamboo under evergreen broad-leaved forest, under deciduous broad-leaved forest, under temperate coniferous forest, under cold-temperate coniferous and mixed forest, and pure bamboo community.

Keywords: Species richness; Species diversity; Life-form; Vascular plant; Altitude
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Introduction

Bamboos are widely distributed in the sub-tropics of China, where several species form the understoreys of mountainous forests (Qin 1985; Campbell 1991; Taylor *et al.* 1993; Taylor and Qin 1996; Zhou and Huang 1996). Most of these bamboos are monocarpic plants and flower synchronously at estimated intervals of 30 to 120 years depending on the species (Janzen 1976; Campbell 1987; Taylor and Qin 1991). On Mount Shennongjia, arrow bamboo (*Fargesia spathacea* Franch.) is the most common bamboo species within an altitudinal belt between 1 200 m and 2 600 m, extending from broadleaved forest in the low elevations till taiga forest on high mountains (Ban *et al.* 1995). Up until the early 19th century, giant panda (*Ailuropoda melanoleuca*) ranged over this region (Loucks *et al.* 2001), feeding on arrow bamboo (*F. spathacea*) and umbrella bamboo (*Fargesia murielae*). So far, several species of national protected animals, e.g. Chinese bamboo rat (*Rhizomys sinensis vestitus*) and red panda (*Ailurus fulgens*), are still depending on underlying bamboos in Mount Shennongjia.

On the other hand, altitudinal gradients are thought to be one of the most general patterns of species and community diversity (e.g. Kessler 2000; Gedalof and Smith 2001). However, it is not yet known whether a general relationship exists between species and elevation in bamboo communities, since bamboo has long been considered as a mono-dominated plant. Due to the lack of studies examining bamboo communities at different spatial scales, three questions are initially addressed as the objectives of this research. Firstly, does altitude influence the floristic pattern of arrow bamboo communities in terms of species richness, species diversity, and species evenness? Secondly, does the altitude affect the life-form spectra over bamboo communities across the elevation? Finally, how does arrow bamboo associate with its host vegetations?

Material and methods

Study area

The study was conducted on Mount Shennongjia (N 31°21'20"~31°30'20", E110°03'05"~110°33'50", Alt. 3 105.4 m) in West Hubei at Central China. The mountain geographically belongs to the eastern branches of the Dabashan Mountain, a transitional belt connecting China's highest morphologic terrace, the Tibetan plateau and the hilly land in central China (Ban *et al.* 1995; Zhu and Song 1999). Along with the altitude, environmental conditions obviously follow a gradient corresponding to the elevation change (Zheng *et al.* 1984; Ban *et al.* 1996). For example, from low valley (e. g. Songpei, 930 m) to high peak (e.g. Observation Tower, 2 930 m), the mean annual temperature decreases from 12.1°C to 2.2°C, average temperature of the coldest month (January) from 0.7°C to -9.4°C, average

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temperature of the hottest month (July) from 22.8ºC to 8.1ºC, and frost free period from 223 day to about 83 day, while mean annual precipitation increases from 965.5 mm to about 2 780 mm. With temperature decrease and moisture increase, the soil also presents a gradient variation along the altitude. Such elevation changes coupled with extreme topographic relief breed and protect more than 2 762 species of vascular plants (Zhu and Song 1999).

Community survey

All field data were collected between April 2000 and July 2001 in Mount Shennongjia within an elevation ranged from 1 500 m to 2 600 m, where *Fargesia spathacea* dominates the understoreys. Measurement of community was mainly conducted in late summer when the vegetation was fully developed and the annual growth of bamboo reached its stable stage. For the vegetation survey, the Zürich Montpellier (Moor and Chapman 1984) approach was followed. A total of 11 plots with areas varied between 200 m^2 and 400 m^2 were set up according to the vegetation type and environmental variation (Table 1), which included an inventory of all plant species and estimates of the percentage of cover for each species. The estimated aerial cover in percentage per species was classified following the Van der Maarel scale (Causton 1988). One modification of this scale was performed by joining classes 1 and 2 into one single class 1. The name of the communities was based on the diagnostic species in the upper layer. Life-form spectra were calculated based on presence data for each species in each life-form category following Raunkiar's system (Causton 1988). Mosses and lichens were excluded. In each plot, several 1×1 m^2 quadrates were surveyed to record the density, height of bamboos, and to measure the coverage of herb species.

Table 1. Plant communities and environmental characteristics of *Fargesia spathacea* stands on Mount Shennongjia in Central China

Item	Plots										
	Fe	Qa	Ac	Pa	Ph	Qs	Pd	Bu	Fs	Af	Aff
Altitude (m)	1680	1750	1820	1850	1905	1960	2000	2400	2450	2460	2570
Exposition	NE	SW	NE	SE	NW	NW	SE	NW	NE	NW	NE
Inclination	35°	18°	27°	55°	41°	23°	57°	63°	14°	30°	12°
Rplot area (m^2)	400	400	400	200	400	400	400	400	200	200	400
Aerial cover (%)	90	95	100	95	100	95	100	85	95	90	100
Overstorey cover (%)	60	70	90	70	80	90	80	80	10	85	40
Understorey cover (%)	80	60	50	50	90	40	70	40	50	60	90
Herb layer cover (%)	20	40	10	10	30	30	50	10	70	10	20
Bamboo cover (%)	60	60	20	40	40	30	20	40	50	60	80
Bamboo density (culms m^{-2})	75	124	12	20	105	37	81	13	57	44	97

Fe indicates the plot in forest of *Fagus engleriana*, *Qa*: Forest of *Quercus variabilis*, *Ac*: Forest of *Abies chensiensis*, *Pa*: Forest of *Pinus armandii*, *Ph*: Forest of *Pinus henryi*, *Qs*: Forest of *Quercus spinosa*, *Pd*: Forest of *Populus davidiana*, *Bu* Forest of *Betula utilis*, *Fs*: Forest of *Fargesia spathacea*, *Af* and *Aff*: Forest of *Abies fargesii*

Data analysis

For analyzing the floristic features of bamboo communities, species richness, species diversity, and species evenness, were compared among 11 plots. Species richness (*S*) was calculated following the formula (Ludwig and Reynolds 1988):

$$S = \frac{Pi}{\sum(Pi)} 100\%$$

where *Pi* indicates the number of species in a given plot and E(*Pi*) indicates the cumulative number of plant species encountered in all plots. Species diversity for each plot was determined by Shannon-Weiner Index (*H´*):

$$H' = -\left[\sum (Pj)(Ln(Pj))\right]$$

where *H´* indicates the Shannon-Weiner Index of the relevant plot; *Pj* means the coverage scale of *j*th species inside a plot; and *Ln(Pj)* means natural log of *Pj*. We calculated the evenness index (*E*) by derived it from the Shannon-Weiner Index (*H´*) and species number (*Sn*):

$$E = \frac{H'}{Ln(Sn)}$$

Detrended correspondence analysis (DCA) was used on CANOCO (CANOCO for Windows 3.1) to analysis the species coverage for classifying the communities. Meanwhile paired samples correlation and linear models were also adapted to test the relationship between floristic features and altitudinal variables. Most of calculations were done on SPSS for Windows 10.0 (2000 SPSS Inc.).

Result and analysis

Species richness, diversity, and evenness

A total of 102 species of vascular plants were encountered in 11 plots of bamboo community. Of these, 40 species are canopy trees, 33 species are woody shrubs, and 29 species are grasses and sedges. Species numbers varied from site to site, ranged from 7 to 30 species $plot^{-1}$. The plots at lower elevation usually have higher species

richness, and at higher altitudes with lower richness(Table 2). Our analysis suggested that the species number (Y) was strongly (r = 0.92) correlated with the elevation (X). A linear model, $Y = 55.99 - 1.83X$ ($d.f.$ = 9, F-value = 48.64, r^2 = 0.84), could significantly (P < 0.001) describe the decline of species with each 100 m increase in altitude (Fig. 1).

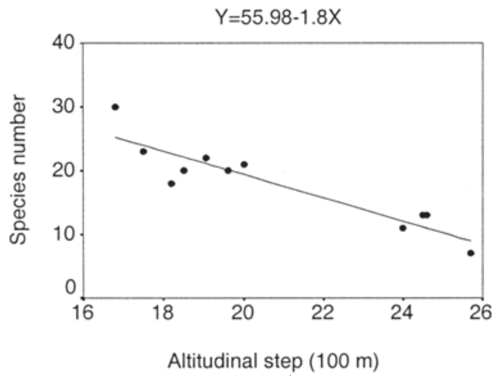

Fig. 1 The relationship between species number of vascular plants and elevation in arrow bamboo (*Fargesia spathacea*) communities on Mount Shennongjia in Central China
Linear relationship takes the equation: $Y = 55.98 - 1.8X$ ($d.f.$ = 9, F-value = 48.64, r^2 = 0.84, P = 0.000).

Therefore we postulated that the gradient in species richness along the elevation might be due to the changes of temperature, growth season, precipitation, and other environmental variables associated with such altitudinal gradient. Species richness is also correlated with its associated vegetations. Deciduous broadleaved forest held more species than that of coniferous forest or shrubs. Nevertheless, species richness was negatively correlated with bamboo cover (r = -0.27).

Species diversity (Shannon-Weiner Index) over arrow bamboo communities was significantly (r = 0.938, P = 0.000) related to the species richness. It followed the similar altitudinal pattern after species richness. Fig. 2 shows the altitudinal pattern of species diversity: $Y = 4.67 - 0.10X$ (r^2 = 0.72, P = 0.001). Species evenness varied from 0.83 to 0.99, however, it was related to neither species richness (r = 0.004, P = 0.991) nor species diversity (r = 0.267, P = 0.447). It seems that the species evenness might be not directly controlled by the elevation (r = 0.112, P = 0.742).

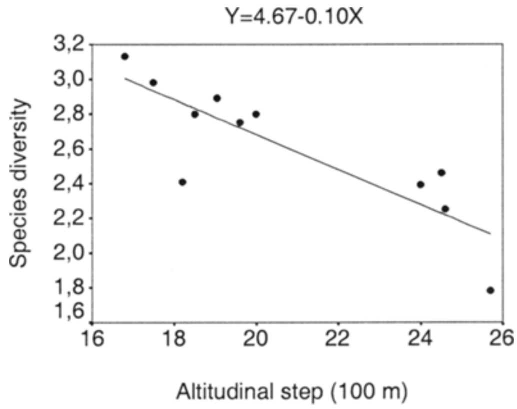

Fig. 2 The relationship between species diversity of vascular plants and elevation in arrow bamboo (*Fargesia spathacea*) communities on Mount Shennongjia in Central China
Linear relationship takes the equation: $Y = 4.67 - 0.10X$ ($d.f.$ = 9, F-value = 22.82, r^2 = 0.72, P = 0.001).

Table 2. Species richness, diversity and evenness of vascular plants in 11 arrow bamboo (*Fargesia spathacea*) communities on Mount Shennongjia in Central China

Item	Plot										
	Fe	*Qa*	*Ac*	*Pa*	*Ph*	*Qs*	*Pd*	*Bu*	*Fs*	*Af*	*Aff*
Elevation	1680	1750	1820	1850	1905	1960	2000	2400	2450	2460	2570
Species	30	23	18	20	22	20	20	11	14	13	7
Richness	0.29	0.23	0.18	0.20	0.22	0.20	0.20	0.11	0.14	0.13	0.07
Diversity	3.13	2.98	2.41	2.80	2.89	2.75	2.80	2.39	2.46	2.25	1.78
Evenness	0.92	0.95	0.83	0.93	0.93	0.92	0.93	0.99	0.93	0.88	0.91

Fe indicates the plot in forest of *Fagus engleriana*, *Qa*: Forest of *Quercus variabilis*, *Ac*: Forest of *Abies chensiensis*, *Pa*: Forest of *Pinus armandii*, *Ph*: Forest of *Pinus henryi*, *Qs*: Forest of *Quercus spinosa*, *Pd*: Forest of *Populus davidiana*, *Bu*: Forest of *Betula utilis*, *Fs*: Forest of *Fargesia spathacea*, *Af* and *Aff*: Forest of *Abies fargesii*

Life-form spectrum

Life-forms are considered types of plants having the same kind of morphological and/or physiological adaptation to a certain ecological factor (Barkman 1988). Based on Raunkaier's life-form classification (Moore and Chapman 1986), our results suggested that in 11 bamboo plots, Mesophanerophytes (MesPh, trees between 8 and 30 m tall) was the most dominant life-form, which contributed 29.9±3.1% (± S. E., hereafter) to the life-form spectrum on average scale. Microphanerophytes (MicPh, trees and shrubs between 2 and 8 m tall) and Chamaephytes (Ch, woody perennials with perennating bud between 0.01 and 0.25 m tall) occupied the second and third place, with contributing 19.8±3.2% and 17.3±2.1% respectively to the life-form spectrum. Meanwhile, Cryptophytes (G, perennials with perennating buds below the surface of the soil), Hemicryptophytes (H, perennials with perennating buds at the surface), Therophytes (Th, annual plant with seeds)

and Megaphanerophytes (MegPh, trees over 30 m tall) respectively made 9.5±2.0%, 9.1±2.1%, 7.8±2.7% and 6.4±1.6% of the life-form spectrum.

However the life-form spectra along the elevation were different. Our results in Fig. 3 show that the altitude might affect the life-form spectrum. Pair samples analysis between elevation and the percentage component of each life-form presents that with the increase of altitude, annual plants (Th, r = 0.60), underground bulb perennials (G, r = 0.40), and big trees (MegPh, r = 0.35) tended to increase; shrubs (MicPh, r = -0.52) and middle-sized trees (MesPh, r = -0.45) tended to decline. However, perennial grasses (H, r = 0.04) and semi- shrubs (Ch, r = 0.03) were probably not related to the altitudinal gradient.

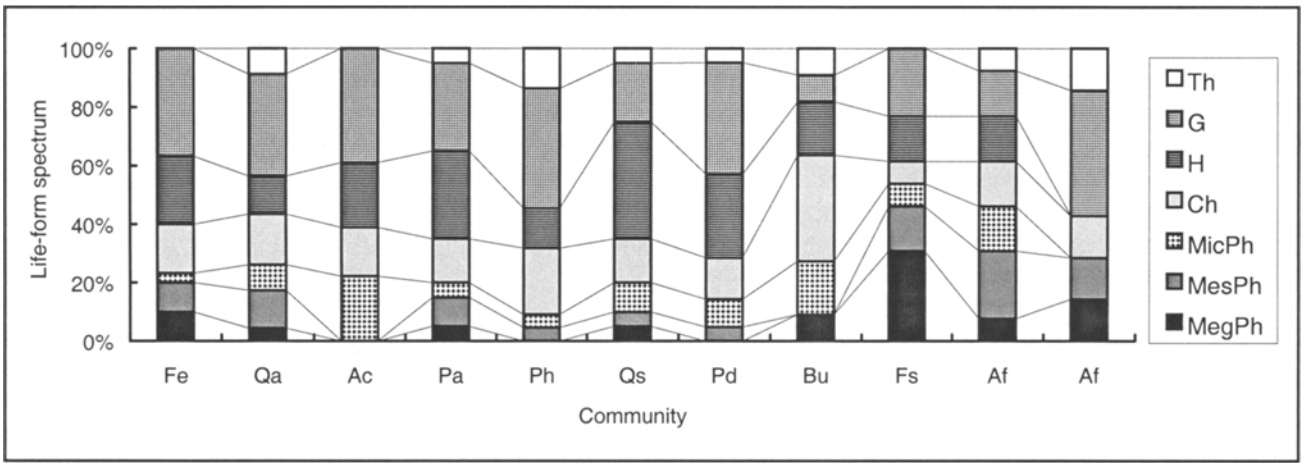

Fig. 3 Life-form spectra of arrow bamboo (*Fargesia spathacea*) communities within an elevation range from 1600 to 2600 m on Mount Shennongjia in Central China.

Therophytes (Th) = annual plants (perennating bud is the seed); Cryptophytes (G) = perennials with perennating buds below the surface of the soil; Hemicryptophytes (H) = perennials with perennating buds at the surface (0 m); Chamaephytes (Ch) = woody perennials with perennating bud between 0.01 and 0.25 m tall; Microphanerophytes (MicPh) = trees and shrubs between 2 and 8 m tall; Mesophanerophytes (MesPh) = trees between 8 and 30 m tall; Megaphanerophytes (MegPh) = trees over 30 m tall. *Fe* = Forest of *Fagus engleriana*, *Qa* = Forest of *Quercus variabilis*, *Ac* = Forest of *Abies chensiensis*, *Pa* = Forest of *Pinus armandii*, *Ph* = Forest of *Pinus henryi*, *Qs* = Forest of *Quercus spinosa*, *Pd* = Forest of *Populus davidiana*, *Bu* = Forest of *Betula utilis*, *Fs* = Pure community of *Fargesia spathacea*, *Af* and *Aff* = Forest of *Abies fargesii*.

Community types

An ordination based on detrended correspondence analysis (DCA) within CANOCO suggests that the arrow bamboo communities could be classified as five groups (Fig. 4).

(I) Evergreen broad-leaved forest: Community of *Quercus spinosa* - *Fargesia spathacea* was found in south-faced slopes between 1 700 m to 2 100 m. Common canopy associates include several deciduous species such as *Fagus engleriana, Acer davidii*, *Populus davidiana*, *Tilia oliveri* and *Betula utilis.* Stand found within Qianjiaping (N 31º24.547', E110º24.657', Alt. 1960 m) exhibited a typical structure of this community: dense tree canopy and thin bamboo layer. Tree layer was usually 18-25 m high, with a canopy cover over 75%, while bamboo layer was 3-5 m high, with a ground cover of about 30% and a density of 37 culms m^{-2}. In the margins of bamboo clumps, shrubs and small trees were developing.

(II) Deciduous broad-leaved forest: Deciduous broad-leaved forest is found all in the altitudinal belt between 1 200 m and 2 200 m on Mount Shennongjia (Zhu and Song, 1999). However, arrow bamboo only dominates the understorey of three forests: forest *Fagus engleriana* (1 700-2 300 m), forest *Quercus variabilis* (1 400-2 000 m), and forest *Populus davidiana* (1600-2300 m). *Fagus engleriana* is multi-stem tree, which colonizes disturbed or degraded sites in the north-faced slopes. Its distribution is discontinuous, with stands limited to moderate sunnier, moist climate, and well-drained sites. *F. engleriana* dominates such stands by associating with *F. lucid, Quercus aliena* var. *thibetica*, *Q. oxyodon*, and some coniferous trees such as *Keteleeria davidiana* and *Picea brachytyla*. Canopy cover of the overstorey was relatively sparse (50%-60%) with a height averaged 15-20 m. Bamboo layer covered about 60% of the forest ground with a mean density of 75 culms m^{-2} and average height of 3-3.5 m. *Quercus variabilis* is a common species widely planted in mountainous areas allover Central China as a raw resource for producing edible fungi (Ban 1995). It is naturally distributed from 500 to 1 800 m on Mount Shennongjia, however, the community of *Quercus variabilis – Fargesia spathacea* only occurs between 1 600-1 800 m. Canopy cover of the dominant overstorey was about 70% with 19 to 25 m in height. The ground coverage and culm height of bamboo layer were similar to those in the forest *F. engleriana*, but culms were much more dense, reached a density of 124 culms m^{-2}. Community *Populus davidiana – Fargesia spathacea* is usually distributed in upper mountains with an elevation between 1 600–2 300 m. It is considered as a degraded

degraded type of coniferous forests (Zhu and Song 1999). Its overstorey was strongly associated with some coniferous trees especially *Pinus armandii* and *P. henryi*. The coverage of bamboo was extremely sparse (20%), but density was moderated (81 culms m^{-2}).

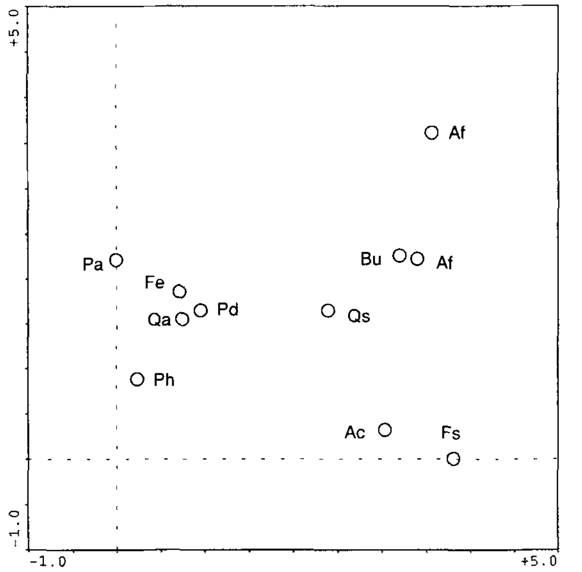

Fig. 4 DCA oridination of arrow bamboo communities on Mount Shenningjia in Central China.

(I) Evergreen broad-leaved forest (*Qs*: Community of *Quercus spinosa - Fargesia spathacea*). (II) Deciduous broad-leaved forest (*Fe*: Community of *Fagus engleriana – Fargesia spathacea, Qa*: Community of *Quercus variabilis – Fargesia spathacea, Pd*: Community of *Populus davidiana – Fargesia spathacea*). (III) Warm-temperate coniferous forest (*Ac*: Community of *Abies chensiensis – Fargesia spathacea, Pa*: Community of *Pinus armandii – Fargesia spathacea, Ph*: Community of *Pinus henryi – Fargesia spathacea*). (IV) Cold-temperate coniferous and mixed forest (*Bu*: Community of *Betula utilis – Fargesia spathacea, Af* and *Aff*: Community of *Abies fargesii – Fargesia spathacea*). (V) Pure bamboo community (*Af*: Community of *Fargesia spathacea*).

(III) Warm-temperate coniferous forest: Mountainous coniferous forests are common on Mount Shennongjia above 1 600 m. *Abies chensiensis – Fargesia spathacea* is a rare community which only scatters in sunnier slopes between 1 500-2 000 m. In particular site, the community was solely dominated by *A. chensiensis*, with a sparse bamboo layer due to high canopy cover (90%). The bamboo layer was very weak and covered only 20% of the ground with an low density of 12 culms m^{-2}. Community of *Pinus armandii – Fargesia spathacea* is common vegetation type occurs in dry hill slopes between 1 700 m to 2 400 m. *P. armandii* is a major conifer in the Shennongjia mountainous ranges. Bamboo layer covered approximately 40% of the ground with a density of 20 culms m^{-2}. Community of *Pinus henryi – Fargesia spathacea* appears between 2 200 m and 2 500 m. Canopy height of *Pinus henryi* was averaged 20 to 26 m. Bamboo layer was fairly sparse (40%), but bamboo culms are very dense (105 culms m^{-2}). Herb layer was weak since a thick mat of undecomposed pine needles covering the forest floor.

(IV) Cold-temperate coniferous and mixed forest: *Abies fargesii* predominates in the upper mountains from 2 500 m extending to the summit of 3 100 m, forming taiga forest (Li *et al.* 1995). Two bamboo species, *Fargesia spathacea* and *Fargesia murielae* dominate the understorey of *A. fargesii* respectively below and upper 2 600 m. *F. spathacea* tends to occur at dry slopes, while *F. murielae* prefers the moist valleys. Ground cover of *Fargesia spathacea* was between 70%-90%, with a moderate density of about 70 culms m^{-2}. When *A. fargesii* had been logged or burnt out, the community might be degraded to a secondary community type, *Betula sp. – Fargesia spathacea*. Important canopy trees of this community include *Betula albo-sinensis, B. utilis, Acer mono, Populus davidana, Sorbus huphensis, and Abies fargesii.*

(V) Pure bamboo community: *Fargesia spathacea* distributed between 2 400 to 2 600 m is frequently presenting as pure bamboo community scattered on the mountainous meadows. It is considered as a degraded community type of fire succession (Ban 1995). Although sometimes associated with shrub species such as *Sorbus huphensis, Crataegus wilsonii*, and *Chaenomeles cathayensis, F. spathacea* exhibited as only dominant overstorey in this community. The herb layer was relatively thick and covered over 70% of the ground. It is not very clear whether this community is a stable type or not. For example, when the parent bamboo clumps mass flowered and died-back, how can the bamboo seedlings competing against such thick herbs? If the seedlings failed, the bamboo community will disappear.

Conclusion

Arrow bamboo (*Fargesia spathacea*) is a common species naturally distributed on Mount Shennongjia, with an elevation range between 1 200 m and 2 600 m. A total of 102 species of vascular plants were encountered in 11 plots of arrow bamboo communities. Of these, 40 species are canopy trees, 33 species are woody shrubs, and 29 species are grasses and sedges.

Species richness of bamboo communities was strongly (r = 0.92) correlated with the elevation. A linear model, Y = 55.99 – 1.83X ($d.f.$ = 9, F-value = 48.64, r^2 = 0.84), could significantly (P < 0.001) describe the decline of species with each 100 m increase of altitude.

Species diversity was significantly (r = 0.938, P = 0.000) related to the species richness and tended to decline with the increase of altitude, following a linear model: Y = 4.67 – 0.10X (r^2 = 0.72, P = 0.001). However, the species evenness was related to neither species richness (r = 0.004, P = 0.991) nor species diversity (r = 0.267, P = 0.447). It seems that the species evenness might be not controlled by the elevation (r = 0.112, P = 0.742).

Along life-form spectra across the arrow bamboo com-

munities, the percentages of annual plants (Th, r = 0.60), underground bulb perennials (G, r = 0.40), and big trees (MegPh, r = 0.35) tended to increase with the increase of elevation; shrubs (MicPh, r = -0.52) and middle-sized trees (MesPh, r = -0.45) tended to decline. However, perennial grasses (H, r = 0.04) and semi- shrubs (Ch, r = 0.03) were probably not directly related to the altitudinal gradient.

Arrow bamboo communities on Mount Shennongjia could be classified as five groups: (I) bamboo under evergreen broad-leaved forest, (II) under deciduous broad-leaved forest, (III) under warm-temperate coniferous forest, (IV) under cold-temperate coniferous and mixed forest, and (V) as pure community.

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